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THE LIFE HISTORY OF THE BLUEGILL SUNFISH, LEPOMIS MACROCHIRUS, OF BUCKEYE LAKE (OHIO)

GEORGE D. MORGAN[1]

Received March 1951

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I. INTRODUCTION

The life history of a fish is a sequence of events which begins with the fertilized egg and continues throughout life until death. A complete life history covers a multitude of facts the analysis of which requires considerable time and a great deal of patience on the part of the investigator. A complete life history should include: a description of the species, distribution, general behavior, the

kind of water preferred, the character of the bottom, the association of the fish with other species, food habits, the spawning period, behavior of the sexes, the number of eggs produced, the viability of the sperm, disposition of the eggs, growth, period of incubation, parasites, competitors and predators, and the economic importance. The complete life history of very few fishes is known. A great deal of work has been done on the various aspects of the life of many fishes. This information is scattered throughout the literature so that a complete picture of most of our fishes is not easily available.

The knowledge of the life history is very important for sound and successful fish management policies. If fish eggs are to be collected for propagating purposes a knowledge of the entire breeding season is essential. If fishes are to be stocked in a stream, farm pond or lake, it is important to know the kind of habitat in which they will thrive, their food habits and their competitors.

At the suggestion of Mr. Lee S. Roach and Mr. Edward L. Wickliff of the Wildlife Division of the Ohio Department of Natural Resources, the writer undertook the task of compiling as much as possible of the information concerning the life history of the bluegill sunfish, Lepomis macrochirus, in Buckeye Lake, Ohio. I am deeply indebted to these officials for valuable information concerning the habits of this species, for making available to me the equipment necessary for such work, for access to test net catch data, and creel census data, and for the help of the department's field workers on all aspects of the project. I am particularly indebted to Messrs. Ray Riethmiller, Richard Norviel, and Joseph Sandbrink for their assistance in the field in locating spawning beds, setting test nets, and for procuring fish from the test nets and many other courtesies. I am also indebted to Mr. Leland Brown and Mr. Paul Chanley, students at Denison University, for their share of the work in the laboratory and for their untiring help in the field.

II. MATERIALS AND METHODS

Fishes examined were collected from test nets and by seining in various parts of Buckeye Lake during late winter, spring, summer and fall of 1949 and 1950. They were removed from test nets every two or three days and taken to the laboratory where they were measured and weighed. Both body weight and gonad weight were determined; and the ratio of body weight to gonad weight was computed during the entire period. The number of eggs in an ovary was determined by counting the number of eggs in a weighed or measured sample, and then computing the total number of eggs using the total weight or volume of the ovary. The volumetric method was used when the eggs could be easily stripped from the mature fish.

Observations were made of the spawning beds at Buckeye Lake, New Lexington reservoir, Clouse Lake, Gravel pit at Granville, the Federal Fish Hatchery at Hebron, and at several farm ponds.

For age and growth studies, scales were removed from over 300 fishes from the region between the lateral line and the anterior end of the spiny dorsal fin. The age and growth of the bluegills were determined by comparing the length

and weight of the fish with the yearly growth as recorded by the annuli on the scales, as described by Lee S. Roach and Irene M. Evans (29).

For food studies the stomachs of about 200 fishes were examined and the food contents determined. Many of the fish taken from the test nets contained little or no food. This was due to the time each fish had been in the net, most of the food the fish had eaten before entering the net having been digested. Seining for large bluegills for food studies was not feasible because of the dense growth of vegetation and the muddy nature of the bottom. However, we were able to secure, from anglers on the lake, the stomachs of many bluegills filled with food. Numbers of small bluegills were caught by seining in the shallow areas along the lake shore.

III. DESCRIPTION OF THE SPECIES

External Characters

Adult bluegills range in length from five to nine inches with some reaching a length of about twelve inches, and a weight of over a pound. The body of the adult is laterally compressed, short and deep. The depth is about one half the length. The mouth is small scarcely reaching the anterior margin of the eye, a character which it shares with the pumpkin seed sunfish and the long eared sunfish. However, the bluegill can be differentiated from the latter by the shorter and broader opercle flap, and also by the absence of any bright colored spots on the side of the body. The dorsal fin is high with 10 spiny rays, and 10 to 12 soft rays. There are also black spots on the last five soft rays (Fig. 1). The pectoral fins are long and pointed. The anal fin has 3 spiny rays and 10 to 12 soft rays. The ventral fins are long and reach, in most cases, as far as the anal fin.

The color of the bluegill is quite variable. Usually light to dark olive green bands alternate with six or more indistinct darker vertical bands. These in some forms are more pronounced. The belly is light yellowish brown with a tinge of blue, changing to salmon color on the breast. This is true in many males during the breeding season. The operculum is a dark mottled blue black, the lower margin a lighter blue green which continues as far as the tip of the lower jaw. The opercle flap is black and is broader than it is long. The bases of all the fins are a dark olive green with the free margins much lighter and having a bluish cast. The anal fin is much lighter in color.

There are no definite external characters which serve to identify males and females. However, during the breeding season some males are much darker in color than the females, and the belly and breast may be deep orange or salmon colored. This is not true of all specimens since there is quite a variation in color among the species. Also during the breeding season the females can be recognized by the fullness of the belly in front of the vent. In gravid females the eggs can be removed easily with a little pressure on the sides of the abdomen. The breeding males also have well filled abdomens and the milt containing the sperms can be removed with a little pressure as with the females.

For external characters used in scientific keys see Figure 1.

Internal Anatomy (Fig. 2)

The floor of the mouth bears a slight elevation which represents the *tongue*. In some sunfish, for instance the warmouth bass and the pumpkin seed, the

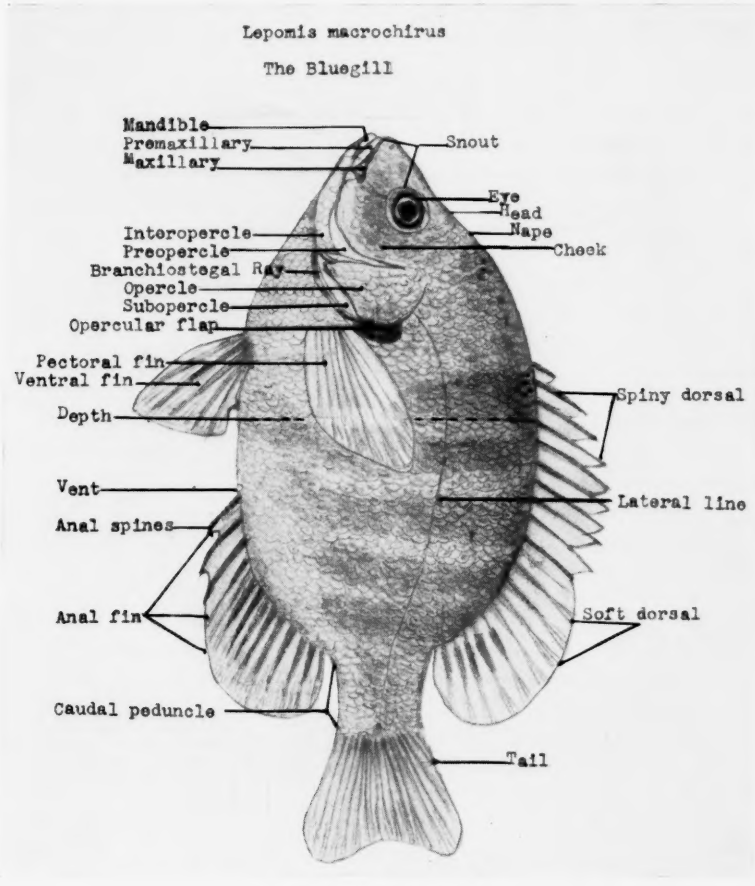


FIG. 1. External characters

tongue and the roof of the mouth bear *teeth*. This is not true of bluegills as the tongue and roof of the mouth are devoid of teeth. Back of the mouth is the *pharynx* with its *gill slits*. The gill arches bear tiny processes called *gill rakers* (Fig. 2) which keep the food from passing out through the gill slits with the water. They are rather long and stiff in the bluegill. Back of the last gill arch on both the roof of the mouth and the floor of the pharynx there are teeth called *pterygoid teeth*. They are slender and sharp in the bluegill, a character which serves to dis-

tinguish it from the pumpkin seed sunfish in which the teeth are more or less blunt. The length of the gill rakers and the character of the pterygoid teeth serve to distinguish bluegill fry from other sunfish fry when other characters appear the same. A short *esophagus* leads from the pharynx to the *stomach* (Fig. 2) which is a dilated sac with a constricted portion at its lower end, the *pylorus*. Attached to the pylorus are several finger-like tubes called *pyloric caeca* which

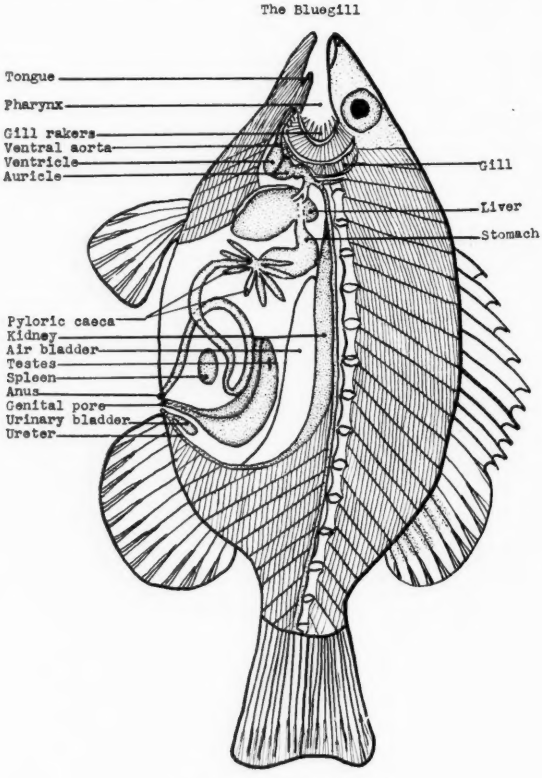


FIG. 2. Internal anatomy

serve to increase the absorptive and digestive surfaces of the digestive tube. From the pylorus the narrow *intestine* extends tailward but soon turns forward again towards the stomach and then tailward again to end as the *anus* a little in front of the anal fin.

The small dark brown organ lying in the folds of the intestine is the *spleen*. The *liver* is quite large and lies in front of the stomach between it and a partition, the *septum transversum*, which separates the *abdominal cavity* from the *pericardial cavity*. The tiny green sac embedded in the liver is the *gall bladder*. It is connected to the intestine by a small duct, the *bile duct*.

The reproductive organs of both sexes lie between the intestine and the *air bladder* to which they are attached. The *ovaries* are closed sacs, or *ovisacs*. The eggs collect within the ovaries and pass directly into the oviducts, that are simply elongations of the hollow ovaries, and to the exterior through the genital pore.

The male reproductive organs, or *testes*, (Fig. 2) are also paired and lie in the same position as the ovaries between the intestine and the air bladder. They taper towards the hinder end and unite to form a common portion which communicates with the exterior by the genital pore just behind the anus. As in the ovaries the size of the testes depends upon the sexual condition of the animal. During the spawning period they are quite large and extend far forward into the abdominal cavity. The male and female gonads can be easily recognized by their color. The testes are usually white in color while the ovaries are yellow to brown and contain the eggs which are easily recognized.

The *kidneys* lie above the air bladder. They are narrow red bands of tissue embedded in the body wall on each side of the backbone. Two ducts, the *ureters*, pass from the kidneys and joint to form a common duct which opens to the exterior through the urinary pore located behind the genital pore. A small *urinary bladder* is attached to the common part of the ureters. It lies between the latter and the gonads.

The *heart* is located beneath the gills in the pericardial cavity (Fig. 2). Hence the heart of a fish is located in its throat. The heart consists of three parts: a large blood sinus, the *sinus venosus*, which receives all the blood from the body; a large *auricle* which receives the blood from the sinus venosus; and a thick walled *ventricle* into which the blood from the auricle flows. When the ventricle contracts the blood is forced into the gills where the exchange of gases takes place. From the gills aerated blood returns to the body.

IV. DISTRIBUTION

The bluegill has a wide range of distribution. It is found in lakes and streams from Western New York throughout the Great Lakes region and Mississippi Valley to Northern Mexico, and along the Atlantic Coast all the way from New York to Florida. In Ohio it is found in most of our lakes and reservoirs and less abundantly in the larger rivers. It is seldom found in the smaller streams, Wickliff and Trautman (39).

V. SCHOOL MOVEMENTS

Judging from the test net catches and creel census reports (Graphs 5, 6, 7, and 8, pages 49 to 50) the bluegills are active along the shore at Buckeye Lake between March and August. The most active periods are in May, June, and July. This activity corresponds to the spawning period (Graphs 2 and 7, pages 33 and 50). Towards the end of the spawning period, in late July and early August, when the temperature reaches 87°F. the activity of the fish reaches a low ebb. This is evident from the test net catch and creel census reports for this period. Exceptional catches during this time of the year are limited to such species as the channel cat, white bass and shad.

During the active period the bluegills travel in schools. One angler caught 130 bluegills in two hours over the spawning beds at Cranberry Bog on May 19, 1949. Most of these were gravid females.

VI. ASSOCIATIONS

The bluegill is associated both diurnally and nocturnally with the black crappies, white crappies, white bass, bullhead catfish and shad during most of the year. They are usually taken together with these fish as indicated by the test net catch (Graph 5).

VII. GENERAL BEHAVIOR

The bluegill, because of its pond loving habits, and its easy adaptability to all kinds of bottom, is an easy fish to propagate. It is one of the favorite fishes in farm ponds where it reaches a good size providing there is a sufficient amount of aquatic vegetation to supply food and cover. Bluegills usually feed near the bottom. The larger fishes seek deeper water. The young fishes like the shallower areas where there is much vegetation for cover and food. Here they nibble at all kinds of bait which the angler may dangle before them.

Manner of Resting

Observations were made on the manner of resting and swimming in a large aquarium in the laboratory. The bluegills rest upon the bottom on their ventral and anal fins while the pectoral fins are moved slowly to aid in balancing. They can remain stationary on the bottom for a considerable period of time, the only movements of the body being the opening and closing of the mouth, and the inward and outward movements of the operculum.

Manner of Swimming

Stationary position in the water. The fish maintains a stationary position in the water by the aid of the air bladder and by the action of the fins. While in this position the pectoral fins are moved slowly backwards and forwards. Sometimes both fins move together. Then they may be moved alternately. The anal and soft dorsal fins are moved slowly sidewise. The ventral fins are held stationary while in this position except occasionally when they may be drawn together and then spread apart.

Backward movement. The backward movement is accomplished by a forward movement of the pectoral fins like the use of oars in rowing a boat backwards. During this movement the tail fin and the anal fin move sidewards and aid in balancing.

Forward movement. The forward movement is accomplished by a swift undulating movement of the body. The pectoral fins are drawn backward, and as the fish gains momentum they are held close to the body. During the forward movement the ventral fins are drawn medially. The tail movements, and the fast undulating movements of the body are the main propelling forces during the for-

ward movement. When stopping, the pectoral fins are held outward and act as brakes while the ventral fins are used to neutralize the tendency for the pectoral fins to cause the fish to nose upward.

Upward and downward movements. According to Walter (40) the upward and downward movements are accomplished by shifting the air in the air bladder from one end to the other by the contraction of the body muscles. The action of the tail, the pectoral fins, and the ventral fins are also important factors. When swimming upward, air is forced to the front end of the air bladder causing the head to rise and the tail to sink. At the same time the pectoral fins are moved alternately as the tail moves sidewards. The pelvic fins are drawn medially since when they are spread apart they have the tendency to prevent the upward movement. The fish holds itself at the surface by the alternating action of the pectoral fins, by the movements of the soft dorsal and anal fins, and by the sideward movements of the tail. In swimming downwards the air in the air bladder is shifted to the tail end. The tail rises as the head sinks downward and the fish swims to the bottom by the action of the pectoral fins, tail fin, and pelvic fins. The latter are spread apart during this movement.

Respiration

The bluegill has four pairs of gills supported by four bony arches. Each gill bears a double row of gill filaments which contain blood capillaries through which the exchange of gases takes place (Fig. 3). Oxygen passes from the water into the blood capillaries, and carbon dioxide passes from the blood capillaries into the water. This is accomplished by diffusion caused by differences in the gaseous pressure in the gill capillaries and the surrounding water. The oxygen pressure being greater in the water than in the blood causes a diffusion of oxygen from the water into the blood. The pressure of carbon dioxide being greater in the blood causes a diffusion of carbon dioxide into the water.

The respiratory surface of the gills is adequate for respiration while the fish is in the water. However, when a fish is taken out of the water this surface is reduced. This is due to the fact that gills lying in a common chamber, as in game fishes, have a tendency to stick together thus reducing the respiratory surface (Fig. 4), and causing asphyxiation. In shark-like fishes the gills lie in a separate chamber. Here the gill septa keep the gill filaments apart thus reducing their tendency to adhere (Fig. 5). These fishes can remain out of the water for a longer period before becoming asphyxiated.

Inspiration. During the process of respiration the walls of the mouth cavity act as a pump. In *inspiration,* (Fig. 6), water containing oxygen is drawn through the mouth into the mouth cavity by the outward movement of the walls of the mouth and throat cavities, while membranes, or valves, on the branchiostegal rays prevent the water from passing out through the opercular openings.

Expiration. During expiration, (Fig. 7), the water in the mouth and throat cavities is forced through the gill slits by the contraction of the mouth and throat muscles, while the branchiostegal membranes open, and the valves along the mouth close the mouth opening.

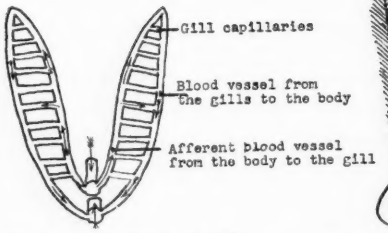


Fig. 3. Blood supply of gills

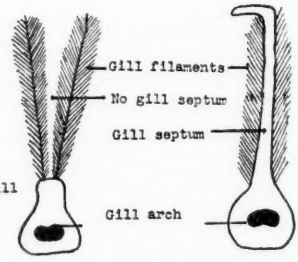


Fig. 4. Game fish gills Fig. 5. Shark gill

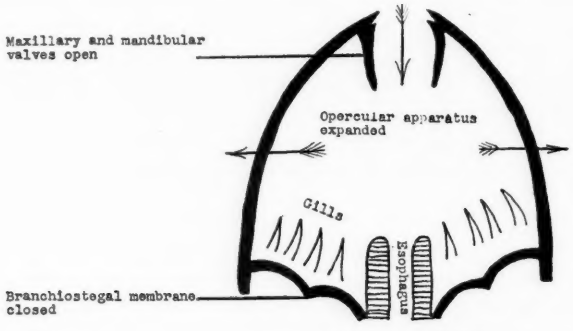


Fig. 6. Inspiration

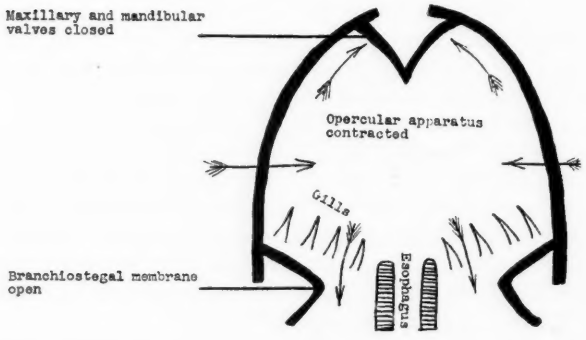


Fig. 7. Expiration

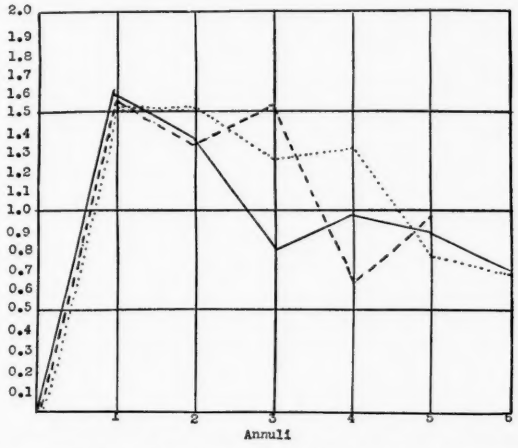
FIGURES 3-7

VIII. REPRODUCTION

The Attainment of Sexual Maturity

According to some workers bluegills that are provided with an abundance of artificial food to supplement the natural food may grow to four inches, and begin to spawn when only one year old. Buckeye Lake bluegills do not attain

this growth until after the formation of the third annulus. In 350 fishes examined, the author and his co-workers found no mature fish until the third year growth. This does not mean that Buckeye Lake bluegills do not mature earlier. The small number of one year old and two year old fishes studied is not enough to justify this conclusion. More investigation is necessary before determining the earliest possible date of maturity of Buckeye Lake bluegills. According to Barney and Anson (4) the orange spotted sunfish, *Lepomotis humilis*, spawns during the second summer (one year old). In our study of the annual growth rates of bluegills from scale annuli we observed that in 80 per cent of the fishes taken there was a sudden drop in the growth rate after the formation of the second, third, and fourth annuli (Graph 1). The average growth rate for the first and second years was 1.55 inches and 1.31 inches respectively. The drop in growth rate after



GRAPH 1. Drop in growth rate after the second, third, and fourth annuli. Drop after 2nd annulus ———. Drop after 3rd annulus — — —. Drop after 4th annulus .....

these years suggests a possible correlation between growth rate and the attainment of sexual maturity. In 25 per cent of fishes with two annuli the growth rate dropped to between 0.61 inch and 1.15 inches. In 34 per cent of the fishes this drop occurred after the third annulus. In 22 per cent of the fishes this drop occurred after the formation of the fourth annulus. This low growth rate continues throughout the life of the fishes in 83 per cent of the cases. The average yearly growth rate of Buckeye Lake bluegills is shown in Tables 1 and 2. If this drop in weight rate at sexual maturity, or after the first spawning period, is valid, it would be a convenient method of determining the age at which a bluegill becomes sexually mature. However, further study must be made before drawing such a conclusion. Barney and Anson (4) state that permanent retardation of growth occurs after the attainment of sexual maturity in the sunfish Elassoma.

Special Male and Female Seasonal Characters

The sex of the bluegill is not easily recognized externally as there is quite a variation in the coloration of the species. However, just preceding and during the spawning period, many males take on a deeper color. The breasts of males with flowing milt may be deep salmon color while in ripe females with heavily swollen abdomens the color of the breast and other parts of the body is much lighter.

Immature bluegills are hard to distinguish from the young of other sunfish. The coloration is much paler than in the adults.

Spawning Period

The beginning and the duration of the spawning period was determined by examination of the gonads of the fish taken from the test nets from early March

TABLE 1

Average Yearly Growth of Buckeye Lake Bluegills (1949)

	YEAR								
	1	2	3	4	5	6	7	8	9
Growth in Inches.....	1.57	1.31	1.24	0.93	0.87	1.04	0.30	0.29	0.78

TABLE 2

Average Yearly Growth of Bluegills at Buckeye Lake as Determined by Lee Roach and Irene Evans (1933)

	YEAR							
	1	2	3	4	5	6	7	8
Growth in Inches.....	1.69	1.23	1.31	1.33	1.19	0.80	0.64	0.56

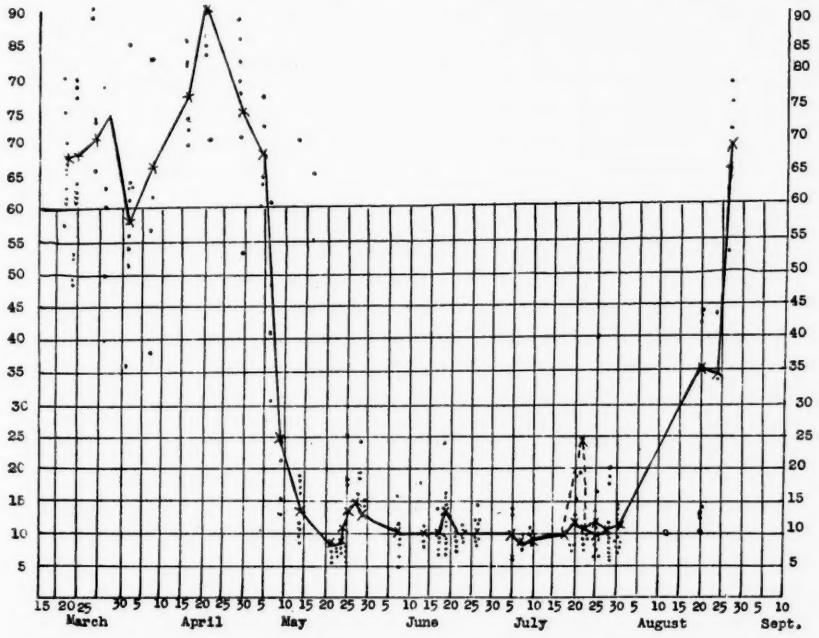
to September. A total catch of 375 was taken at intervals of a few days and dissected in the laboratory after determining the length, and the ratio of body weight to ovary weight.

In considering the duration of the spawning period a convenient index is the ratio of body weight to ovary weight. This is obtained by averaging the ratios acquired by dividing the total fish weights by the weights of the ovaries for each day. The average of the fish-ovary weight ratios was taken as the relative spawning activity for that day. The index was calculated approximately every other day during the summer, and the fish-ovary-weight ratio (relative spawning activity) was plotted against the advancing season (Graph 2).

Mature eggs are ordinarily found in fish with a ratio lower than eight. Ripe females can be stripped of their eggs easily with a little pressure on the sides of the abdomen. The average ratio for all fish is about 9 to 10. When the average fish-ovary-weight ratio is above 15 spawning is at a low ebb or has ceased al-

together. The advantage of the index is that when graphed it shows the peaks and the depressions in the spawning activity during the summer.

The spawning period of the bluegills in Buckeye Lake during 1949 began the second week in May and extended through the summer at intervals until the middle of August (Graph 2). In 1950 the spawning period of the bluegills began a week later and extended through August 20. Gravid females were taken out of the net at Lieb's Island, Buckeye Lake, on August 20. The later spawning period for 1950 may be due to the unusually cool summer. The temperature of the



GRAPH 2. Ratio of fish weight to ovary weight versus time of the summer. · Ratio of each fish. × Average ratio for the day.

water during the spawning period for 1949 varied from 67 degrees Fahrenheit to 87 degrees Fahrenheit (Graph 5). The peaks of the spawning occur during the middle of June and in early July (Graph 2).

From our scale studies of 299 fishes we found that during the first summer there is a marked variation in the growth rate of bluegills of all ages. The length to the first winter annulus varies from 1.12 inches to 2.38 inches (Table 3). This variation also was present in 37 one year old bluegills studied, the variation in growth being between 1.13 inches and 2.21 inches (Table 4).

This variation of growth of fish of all ages during the first summer may be due to the date of hatching. Fish that hatch early in the summer have a longer period

to grow than those that hatch during the middle and late summer. It is interesting to note (Graph 2) that there are several spawning peaks during the summer to which the different size groups may belong. However, more data is necessary before drawing definite conclusion concerning the relation of the spawning date to the variations in growth rate during the first summer. It is recognized that variations in growth occur even in young fish of the same hatch.

TABLE 3

Growth Groupings of Fish of All Ages at the First Annulus

GROUP	NUMBER	AVERAGE SIZE	SIZE RANGE (INCHES)	PER CENT
1	3	2.34	2.30–2.38	1.00
2	13	2.15	2.07–4.31	4.31
3	29	1.95	1.87–2.03	9.70
4	48	1.78	1.72–1.85	16.02
5	39	1.65	1.61–1.70	13.04
6	63	1.53	1.46–1.60	21.07
7	45	1.39	1.33–1.45	15.05
8	39	1.28	1.24–1.32	13.04
9	20	1.17	1.12–1.22	6.68
Total.....	299	1.57	1.12–1.38	99.91

TABLE 4

Growth Groupings of One Year Old Fish at the First Annulus

GROUP	NUMBER	AVERAGE SIZE	SIZE RANGE (INCHES)	PER CENT
1	0	0	0	0
2	1	2.21	2.21	2.70
3	2	2.02	2.00–2.04	5.41
4	4	1.79	1.74–1.85	10.81
5	7	1.65	1.61–1.70	18.92
6	3	1.54	1.53–1.55	8.11
7	9	1.38	1.34–1.42	24.32
8	8	1.28	1.24–1.31	21.62
9	3	1.17	1.13–1.21	8.11
Total.....	37	1.51	1.13–2.21	100.00

Some workers are of the opinion that the same bluegills may spawn more than once during the summer. We found no evidence to substantiate or to contradict this view.

Concerning the extended spawning period from May to late August the author is of the opinion, given by Barney and Anson (4) on the spawning period of the orange spotted sunfish, that the extended spawning period of the bluegill may also be due to the date of hatching. Those that hatch early in the summer mature

and spawn late in the third summer (2 years old), while those that hatch middle and late summer spawn early the fourth summer when three years old. However, more data is necessary before definite conclusions are drawn.

Nest and Spawning Habits

During the summer observations were made of the spawning beds at Edgewater Beach, Cranberry Bog, and Fisher's Beach at Buckeye Lake, and at New Lexington Reservoir, Clouse Lake, and the gravel pit at Granville. The nest of the bluegill is quite similar to the nests of other sunfish. The nests at Edgewater Beach were along the shore in sand and small pebbles in depths varying from one to three feet. At Cranberry Bog the nests were bowl-like depressions made in the vegetation at the bottom in three to five feet of water. At New Lexington nests were located along the shallow East shore line in masses of dead leaves, sticks and mud. Richard Norviel, Fish Production Foreman at Buckeye Lake, claims that he has seen bluegills nesting in mud along the dry dock in five to six feet of water. Anglers at this time were catching the spawning bluegills as fast as they could rebait.

The nests vary in size from eight inches to two feet in diameter and a depth of two to three inches. The nests are sometimes solitary but in most cases they were in colonies, and some were associated with other sunfish.

The nest is made by the male fish. The excavating is accomplished by a pushing action of the head and a flipping of the tail. As the small pebbles and sand are flipped outward from the bottom and sides, the larger pebbles from the sides settle to the bottom of the depression. During this activity the scales along the sides of the male may be bruised through contact with the gravel. The bruised areas on the sides of male bluegills caught in test nets at this time are probably due to these nest making activities.

The males lure the females on to the nest where the mature ova are released into the water. As the fishes approach the nest they splash about, the male nudging the female at the vent with his head. They eventually turn over on their sides with the vents approximated and the spawning act is performed. The eggs and the milt containing the sperms pass into the water. Fertilization takes place immediately as the eggs slowly settle into the nest. At this time numbers of large and small sunfish dart in to devour the eggs. The male bluegill dashes about, seemingly in all directions at once, until he has driven away the intruders from the nest. He then stands guard above the nest darting first in one direction and then in the other direction whenever an enemy approaches. When I approached the nest the fish darted away into deeper water. However, when I started to remove some eggs from the nest one male rushed in and struck my hand with his head, much to my surprise. While guarding the nest the male occasionally moves about the nest fanning his tail sidewise. This probably keeps the silt from settling on the eggs and also keeps the water moving over the eggs, serving to aerate them. The eggs are slightly adhesive and stick to the pebbles, small rocks, sticks and leaves that may be present in the nest.

The eggs of the bluegill are about 1.26 millimeters in diameter (Figure 1, Plate 1). The perivitelline space is about .045 mm. in diameter. The yolk is granular and contains a very large oil globule at one end and a disc of protoplasm which caps the yolk at the other end.

The number of eggs in a mature fish varies with the age and size from 2540 in a fish 4 to 4½ inches in length, to 64,000 in a fish 9¼ inches in length. The average number of eggs per fish was around 18,300. Tables 5 and 6 are arranged to show the various lengths for each weight group and vice versa, the age of each

TABLE 5

Egg Production in Age and Weight Groups

LENGTH GROUP (INCHES)	AVERAGE WEIGHT (GRAMS)*	NUMBER OF FISH EXAMINED	PERCENTAGE	AVERAGE NUMBER OF EGGS	FISH WITH RIPE EGGS	TOTAL NUMBER OF EGGS	
4–4½	27.3	4	1.93	2,540	1	2,540	
4¾	34.8	11	2.70	8,332	2	16,664	
5	40.6	33	5.48	9,720	6	58,332	
5¼	47.0	25	7.78	10,040	5	50,211	
5½	57.5	23	9.34	18,796†	7	131,575	
5¾	60.1	20	7.38	12,406	11†	136,466	
6	70.5	8	7.78	15,444	4	61,777	20%
6¼	75.1	15	3.85	13,615	4	54,461	
6½	96.4	17	5.44	17,556	5	87,778	
6¾	100.0	20	7.38	19,288	6	115,728	
7	114.5	21	10.90	21,723	8	173,784	45%
7¼	126.2	14	8.53	21,891	12	262,694	
7½	138.4	12	12.03	23,464	8	187,709	
7¾	147.7	10	3.48	25,417	4	101,670	
8	180.5	4	2.32	29,769	4	119,076	
8¼	170.3	4	1.15	?	none taken	?	22%
8½	178.1	8	1.15	48,500	1	48,500	
8¾–9¼	213.9	5	1.55	49,400	2	98,800	
Total.....		257	100.17	18,300‡	90	1,658,679	

* This column includes the averages of both fishes with mature eggs and without.

† Abnormally above the expected value.

‡ Average of both Table 5 and Table 6.

group, the number of fish in each group, the percentage of fish found in each group examined with the total percentage computed for each of the four larger groups, the average number of eggs per fish in each group, the number of fishes with mature eggs, and the total number of eggs produced by each group.

Note that the largest egg producing group is that between 6¾ inches and 7½ inches (Table 5) or approximately between 100 grams and 140 grams (Table 6). This group produces, as an average of the two tables, approximately 40 per cent of the total, while the length groups below and above this group produce 20 per cent and 18 per cent respectively.

The number of eggs in a nest varies with the size of parent fishes and on how successful they were in keeping away predators. We counted close to 5000 eggs in one nest. This is not quite accurate since it is practically impossible to remove all of the eggs.

TABLE 6

Egg Production in Age and Weight Groups

WEIGHT GROUP (GRAMS)	AVERAGE LENGTH (INCHES)	NUMBER OF FISH EXAMINED	PERCENTAGE	AVERAGE NUMBER OF EGGS	FISH WITH RIPE EGGS	TOTAL NUMBER OF EGGS	
20– 29.9	4½	4	1.50	2,540	1	2,540	
30– 39.9	4¾	11	4.35	8,230	3	24,690	
40– 49.9	5¼	33	12.90	10,500	10	105,000	
50– 59.9	5½	25	9.87	11,257	8	90,056	
60– 69.9	5¾	23	9.06	14,656	9	131,904	
70– 79.9	6¼	20	7.90	14,222	9	127,998	20%
80– 89.9	6½	8	3.16	12,379	3	37,137	
90– 99.9	6¾	15	5.93	15,480	4	61,920	
100–109.9	7	17	6.72	14,525	8	116,200	
110–119.9	7	20	7.90	35,380*	6	212,280	36%
120–129.9	7¼	21	8.28	18,240	10	182,400	
130–139.9	7¼	14	5.52	30,348	4	121,392	
140–149.9	7½	12	4.73	28,733	3	86,199	
150–159.9	7½	10	3.95	30,600	2	61,200	14%
160–169.9	7¾	4	1.50	33,776	1	33,776	
170–179.9	8	4	1.50	31,925	2	63,850	
180–189.9	8	8	3.15	31,060	5	155,300	
190–	8½	5	1.93	45,733	3	137,199	
Total		254	99.85	†	91	1,750,021	

* Abnormally above the expected value.

† Average of both table 5 and table 6 is shown in table 5.

Viability of the Sperms

There is a great variation in the viability of sperms in fishes. Haempel gives the duration of the independent life in the water of sperms of certain fishes as follows:

Trutta fario, L.	23 seconds
Trutta viridea, W. Gibb	40 seconds
Trutta salar, L.	45 seconds
Salmo hucho, L.	45 seconds
Barbus fluviatilis, Ag.	120 seconds
Esox lucius, L.	3–4 minutes
Cyprinus carpio, L.	5 minutes

The viability of the sperms of the bluegills observed in the laboratory varies from 8 to 12 minutes. This is the time that they remain active under the microscope and does not mean that they are capable of fertilizing the eggs during this

entire period. By way of comparison it may be stated that the human sperm may remain active three days after the death of the individual, and in the female genital tract for a week or more. The sperms of the bat remain alive and efficient from the time of mating in the autumn until the following spring when the eggs are fertilized.

IX. EMBRYONIC DEVELOPMENT

Period of Incubation

Mature fishes were stripped of their eggs and sperms in the laboratory by applying pressure to the sides of the abdomen. The eggs and sperms were mixed together in culture dishes in tap water at 72°F. Fertilization took place immediately. Some of the fertilized eggs were placed in an aquarium. Most of them were kept in culture dishes where they could be observed easily with the binocular microscope. It is important not to crowd the eggs in the dishes. The water was changed every few hours and kept at 72°F. as nearly as possible.

Observations were made of the developmental stages from the fertilized egg through eight days after hatching. Most of the drawings were made from direct observations of the living specimens. Specimens at different stages of development were removed. Some of these were fixed in Bouin's solution. Others were fixed in formalin. These were stained in borax carmine and in haemotoxylin and eosin for a more detailed study of development which will be taken up later.

All the fertilized eggs do not develop at the same rate even though fertilization had to take place within twelve minutes. Some of the eggs had reached the early blastula stage while others were still in the two or four cell stage.

The hatching time of the bluegill kept in culture dishes at a temperature of 72° to 74°F. varies from 31 hours and 50 minutes, when the first one hatched, to 62 hours. This time is much shorter than the 5 day hatching time reported by B. L. Barney and B. J. Anson (4) for the orange spotted sunfish. However, it is much nearer the hatching time of the goldfish *Cassius auratus* recorded by Helen I. Battle (3). The hatching time for the goldfish is as follows:

In the laboratory.....	72 to 96 hours at 65.5°F. to 84.1°F.
In lake water.....	64 to 72 hours at 75°F. to 82.5°F.

Cleavage Stages

Immediately after fertilization the blastodisc appears to constrict at the margins forming a white cap on top of the yolk (Fig. 1, Pl. 1). In 35 minutes after fertilization the first cleavage furrow appears, dividing the blastodisc into two blastomeres of about equal size (Fig. 2, Pl. 1). Twenty minutes later a second cleavage furrow appears at right angles to the first to form the four cell stage (Fig. 3, Pl. 1). The 6 to 8 cell stage appears about 77 minutes after fertilization. From now on cell division becomes more rapid and irregular. At one hour and twenty minutes the blastodisc consists of 16 or more cells (Fig. 5, Pl. 1). Twenty minutes later the early blastula is evident (Fig. 6, Pl. 1). The cells of the blastoderm are now quite small. In three hours the marginal cells are beginning to en-

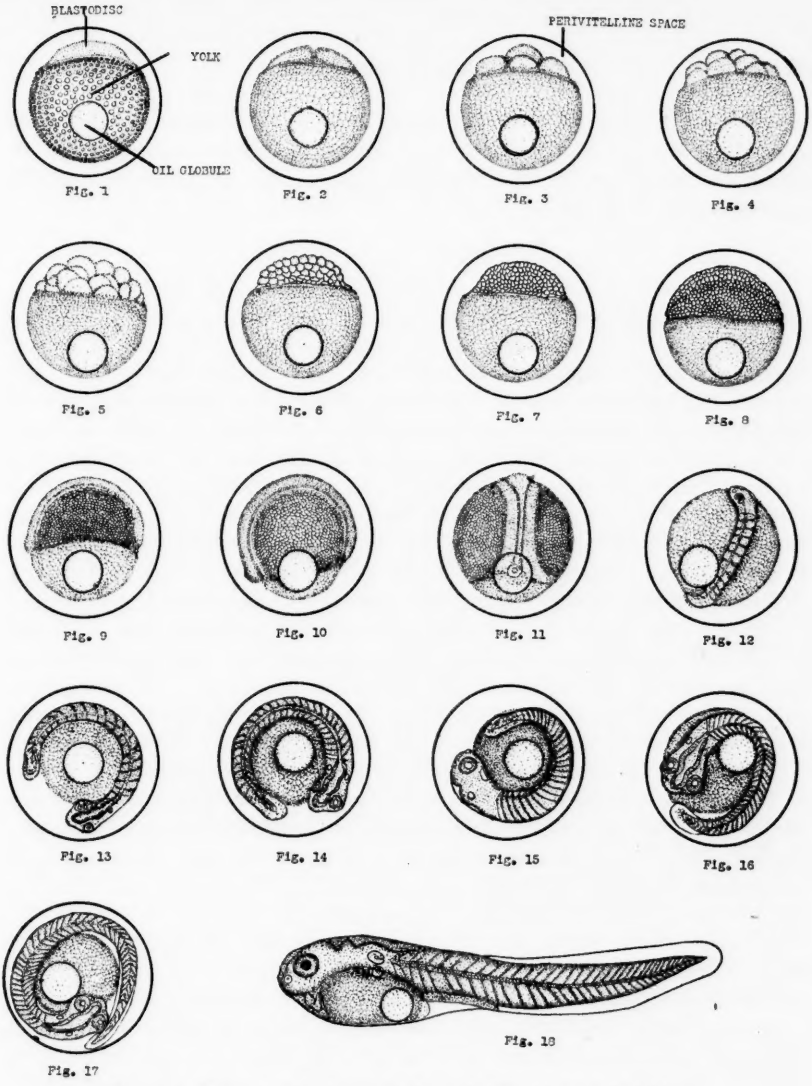


PLATE 1. Stage in development from fertilization to hatching

FIG. 1. Fertilized egg.
FIG. 2. Two cell stage. 35 mins.
FIG. 3. Four cell stage. 55 mins.
FIG. 4. Eight cell stage. 1 hr. and 17 mins.
FIG. 5. Twelve to sixteen cell stage. 1 hr. and 20 mins.
FIG. 6. Early blastule. 1 hr. and 40 mins.
FIG. 7. Many celled blastoderm. 3 hrs.
FIG. 8. Blastoderm cells have covered half the yolk. 4 hrs.
FIG. 9. Early embryo side view. 6 hrs.
FIG. 10. Embryo lateral view. 9 hrs.
FIG. 11. Embryo dorsal view. 11 hrs.
FIG. 12. Embryo of 10 to 12 somites. 17 hrs.
FIG. 13. Embryo of 20 to 22 somites. 21 hrs.
FIG. 14. Embryo of 25 to 27 somites. 25 hrs.
FIG. 15. Embryo of 28 somites. 26½ hrs.
FIG. 16. Embryo of 32 somites. 29 hrs.
FIG. 17. Embryo of 33 to 35 somites. 31 hrs. and 40 mins.
FIG. 18. Just hatched. 31 hrs. and 50 mins. Length 2.79 mm.

close the yolk (Fig. 7, Pl. 1). By four hours they have reached the equator of the yolk. By nine to eleven hours the yolk is almost completely covered except for the yolk plug, and the outline of the developing embryo can be seen through the egg membrane (Figs. 10 and 11, Pl. 1).

Differentiation of the Embryo

Eleven hours. The embryo is now beginning to take shape (Fig. 11, Pl. 1). It appears as a narrow band extending from the blastopore around the yolk. The beginning of the head is evident as an oval expansion.

Seventeen hours. Ten to twelve somites are now present. The body is more elongate and has a definite shape. The brain is visible, and optic evaginations are evident laterally. The embryo reaches over two thirds of the yolk (Fig. 12, Pl. 1).

Twenty-one hours. The body movements are evident. It moves about four times a minute twisting sidewise and bending at the middle of the body. The otic capsule is present back of the eye, and the brain is three parted. The notochord can be seen extending from the region of the otic vesicles back into the tail. The tail is now free from the yolk (Fig. 13, Pl. 1).

Twenty-five to twenty-six hours. The embryo has now almost completely encircled the yolk (Figs. 13 and 14, Pl. 1). It moves about four times a minute. It twists its body sidewise so that its tail touches the head. Both the tail and the head are now free from the yolk mass. There are about 25 to 28 body somites present. The eyes are much larger. Blood can be seen circulating over the yolk into the heart which lies just in front of the yolk sac. The heart beats very rapidly. The blood is quite clear indicating little or no hemoglobin present.

Twenty-nine to thirty hours. The embryo has now encircled the yolk. The eyes and auditory vesicles are more pronounced. The movements of the body are more vigorous, very rapid jittering movements, about twelve rapid shivering movements at a time. The heart still beats very rapidly. The blood is still clear and can be seen flowing over the yolk into the heart and along the dorsal aorta. The yolk sac is getting smaller. The oil globule remains the same size. There appear to be no pigment cells present in the body (Fig. 16, Pl. 1).

Thirty-one hours and fifty minutes. The movements of the embryo are quite vigorous, one shivering movement following another. Suddenly by a vigorous movement of the body the egg membrane ruptures near the head and collapses. Another violent movement and the young larva seem to pop out of the collapsed egg membrane. Some of the newly hatched larvae begin immediately to swim about in circles on their sides. This circling movement is due probably to the large amount of yolk present which hinders movement and acts as a sort of a pivot. Others remain quiet lying on their sides for some time. They swim by an undulating movement of the body and are quite active for a short period, after which they rest a while and move again. The bluegill larva assumes the natural position of the body in swimming very soon after hatching, while the green sunfish swims on its side until about a week after hatching. The auricle and the ventricle of the heart are now well developed. The blood is now red indicating the presence of hemoglobin. A continuous median fold extends along the back around

the tail to underside of the body to the region of the vent, and forward from the vent to the yolk sac (Figs. 17 and 18, Pl. 1). Total length (head to tail), 2.79 mm.; length before the vent, 1.53 mm.; length behind the vent, 1.26 mm.; depth before the vent 0.63 mm.; length of head, 0.63 mm.; diameter of eye, 0.13 mm.; yolk sac 0.9 mm.

Larva and Post-larva Development

3.51 millimeter stage (Fig. 1, Pl. 2). Sixteen hours after hatching. Total length 3.51 mm.; length before the vent 1.69 mm.; behind the vent 1.98 mm.; diameter of the eye 0.22 mm.; yolk sac 0.99 mm. The only pigmentation evident is in the eyes. Tiny pectoral fins have developed and can be seen directly above the yolk sac. The gut can be followed from the region of the yolk sac to the vent. The skeletal axis can be seen through the body extending from behind the auditory vesicles to the tail. The auricle and ventricle of the heart are bent to about a right angle with the auricle right in front of the yolk sac. The gill arches are now clearly evident in front of the yolk sac above the heart. The yolk sac with its large oil globule is still quite large. The brain is now five parted. The cerebral hemispheres, diencephalon, mid brain, cerebellum and medulla oblongata are differentiated. A sac, the air bladder appears above the yolk sac.

3.96 millimeter stage. Two days and four hours after hatching. Length 3.96 mm.; length before the vent 1.84 mm.; behind the vent 2.11 mm.; diameter of the eye 0.27 mm.; yolk sac 0.76 mm.; oil globule 0.27 mm. The air bladder is larger. The yolk sac is becoming smaller. The blood is a deeper red in color containing more hemoglobin.

4.54 millimeter stage (Fig. 3, Pl. 2). Age three to three and a half days. Total length 4.54 mm.; length before the vent 1.98 mm.; length behind the vent 2.56 mm.; diameter of the eye 0.36 mm.; yolk sac 0.72 mm.; oil globule 0.22 mm. The eyes are quite deeply pigmented. The auditory vesicles are larger with otoliths present. The pectoral fins are longer. Swimming movements are more active but the still quite large yolk sac is a hindrance to these movements. There is very little pigment present in the body. Tiny ray-like structures are appearing in the tail fin. The mouth is better developed. The lower jaw is now slightly movable. The heart action is very rapid.

Figure 4, Plate 2, is a different fish. Its total length, 4.54 mm., is the same as the preceding fish, which is a day older. The organs in this fish are better developed. Tiny fin rays are present in both the dorsal and anal fins. The mouth is also better developed and the lower jaw is quite movable. Pigment cells are also present in the ventral and dorsal walls of the body. This fish died when six days old.

4.75 millimeter stage (Fig. 5, Plate 2). Age 6 days 9 hours. The yolk sac and oil globule have become so much reduced that they are practically gone. The opercle is present. Mesenchyme cells are present in both dorsal and anal fins. The tail fin is better developed. The lower jaw is quite movable. More pigment cells are present along the dorsal and ventral parts of the body. The gut can now be followed all the way to the pharynx.

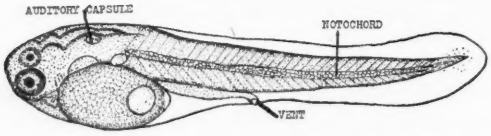


FIG. 1. 3.51 MM. STAGE. 16 HOURS AFTER HATCHING.

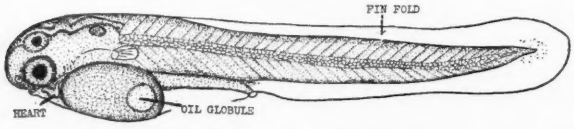


FIG. 2. 3.96 MM. STAGE. 2 DAYS AND 4 HOURS.

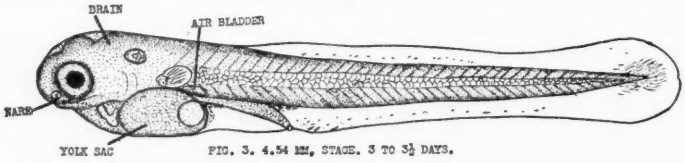


FIG. 3. 4.54 MM. STAGE. 3 TO 3½ DAYS.

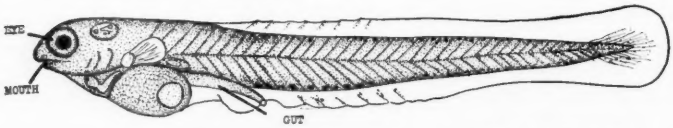


FIG. 4. 4.54.MM. STAGE. 4½ DAYS(NOT THE SAME FISH AS THOSE ABOVE)

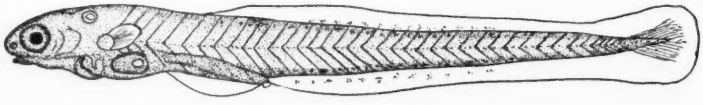


FIG. 5. 4.75 MM. STAGE. 6 DAYS AND 9 HOURS.

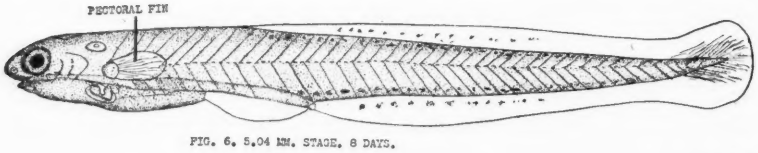


FIG. 6. 5.04 MM. STAGE. 8 DAYS.

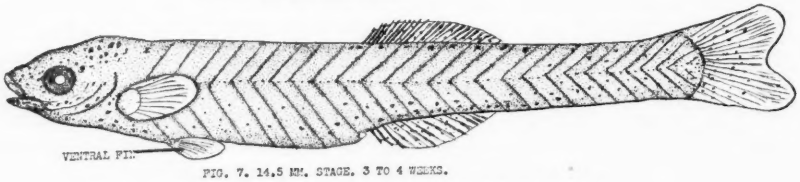


FIG. 7. 14.5 MM. STAGE. 3 TO 4 WEEKS.

PLATE 2. Larva and post larval development

5.04 millimeter stage (Figure 6, Plate 2). Age 8 days after hatching. Total length 5.04 mm.; length before the vent 2.11 mm.; length behind the vent 2.92 mm.; diameter of the eye 0.315 mm. The yolk sac and the oil globule have completely gone. There is no evidence yet of the development of the ventral fins.

14.5 millimeter stage (Figure 7, Plate 2). Age 3 to 4 weeks. Total length 14.5 mm.; length before the vent 6½ mm.; length behind the vent 8 mm.; greatest depth 2¾ mm.; diameter of the eye 1.2 mm. All the fins are now developed. The ventral fins are small but all the spines and rays are present. Pigment cells are present on the head, opercle, jaws, fins and on the body. The scales have not developed yet. The young fry are now quite active and travel in schools.

Care of the Fry

The male bluegill guards the nest for several days, and since the eggs hatch in about 1½ days the helpless larvae are thus given some protection from predators. When they hatch they are not capable of much action. Handicapped by the large amount of yolk to which they are attached and the absence of fins they can only move about short distances at the bottom of the nest. As soon as the yolk is absorbed and the fins have developed the young fry rise from the nest and remain in schools hiding in the vegetation along the shore. During this time they are on their own. The male bluegill does not appear to be in the vicinity.

The number of fry in a school varies with the number of eggs produced by the different sized fishes. Carbine (8) found that a nest contained 4670 to 61815 fry, the average being 17917. Mr. Oldham of the Federal Fish Hatchery at Hebron places the average school in their ponds at about 5000. Mr. Krandle, Director of the hatchery, uses the middle sized fish as breeders. There is quite a mortality between the number of eggs produced and the number of fry in a nest. Many of the eggs and fry are eaten by fishes and other predators, so that a good hatch is around 5000 fry for a medium sized fish.

IX. YEARLY RATE OF GROWTH OF THE BLUEGILL

For growth studies scales were taken from 300 fishes from the area above the lateral line just anterior to the dorsal fin. The scales were projected on a screen and the annuli counted. The method used, as already described, was to measure the distance from the focus to the margin and multiply by the length of the fish from which the sample was taken.

The scales examined came from fish having one to nine annuli. The fish used were not selected. However, most of the fish were taken from six foot nets having wide mesh. Hence the number of fishes taken would include only those large enough to be caught in the net. All the one and two annuli fish in this study were taken by seining. Therefore only fish having three to nine annuli are included in determining age percentage of the bluegill population in Buckeye Lake. Table 7 shows the number of fishes included in the survey by annuli. Disregarding the number of fishes captured by seining it would appear that about 70 per cent of the bluegills in the lake were in the groups with four, five, or six annuli.

An annulus on each scale indicates the growth retardation of the fish during

the winter. Therefore it is possible to tell the age of the fish by the number of annuli present on the scale. A fish with a certain number of annuli is not always the age indicated by this number. For example, a fish hatched in August will acquire its first annulus during the coming winter yet the fish will not be a calendar year old until the following August. Most of the fish in this survey were taken during the spawning period and therefore had grown approximately one year for each annulus. Therefore in this description an annulus is considered one year's

TABLE 7

Number of Fishes Included by Annuli in the Survey

	ANNULI								
	1	2	3	4	5	6	7	8	9
Number	37	2	31	80	78	69	26	6	3

TABLE 8

Variations in Growth Rates Due to the Time of the Year

MONTH		ANNULI								
		1	2	3	4	5	6	7	8	9
April	Average length	1.57	2.92	4.10	5.16	5.95	6.41	6.81	7.32	8.05
	Number of fish	27	27	27	24	18	11	6	2	1
May	Average length	1.52	2.75	4.01	5.12	6.08	6.71	7.47	7.72	
	Number of fish	72	40	40	37	31	18	6	2	
June	Average length	1.56	2.84	4.04	5.01	6.03	6.72	7.46	7.99	8.83
	Number of fish	83	138	194	221	139	94	30	16	17
July	Average length	1.57	2.93	4.13	5.15	6.09	6.90	7.25	7.31	
	Number of fish	94	94	94	84	55	29	11	2	
August	Average length	1.66	3.02	4.13	5.00	5.96	7.14	7.83	8.18	
	Number of fish	24	24	24	22	20	11	3	1	
Sept.	Average length	1.64	2.95	4.27	5.37	6.19	7.34	8.30		
	Number of fish	27	27	27	22	12	6	2		

Average length is in inches.

growth unless otherwise stated. Table 8 illustrates the difference in monthly growth rates between annuli. In this table it is apparent that the growth rate generally increases as the summer progresses. For example, fish caught in April are shorter than those caught in August and September even though they have the same number of annuli.

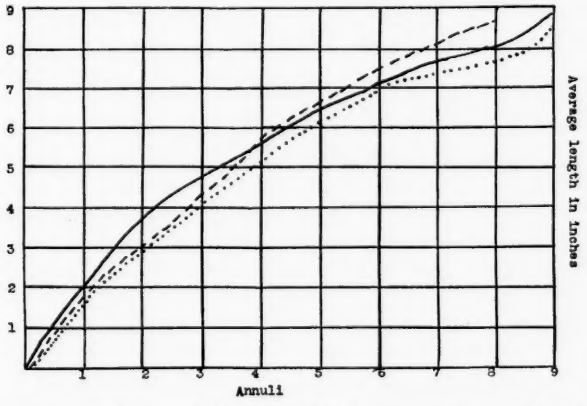
In order to determine the average length of a fish in each age group two records were kept. Table 9 and Graph 3 give the average length of a fish at each annulus plus the growth of the summer before the next annulus.

Table 10 is obtained from determining the length of the fish at each annulus. In this way a yearly record of growth is obtained for each fish. Both of these records vary somewhat from those reported by Lee Roach and Irene Evans (28) as shown in the following Table 11 and Graph 3.

TABLE 9

Average Length (Inches) of Fish at Each Annulus Plus Growth Before Next Annulus

	ANNULI								
	1	2	3	4	5	6	7	8	9
Length	2.01	3.66	4.74	5.52	6.50	7.31	7.72	7.96	8.83



GRAPH 3. Average yearly growth for 1938 and 1949. ——— Average length at each annulus plus the growth before the next annulus. ..... Average length at each annulus. — — — Average length at each annulus (Lee Roach 1938).

TABLE 10

Average Length (Inches) of Fish at Each Annulus

	ANNULI								
	1	2	3	4	5	6	7	8	9
Length	1.57	2.88	4.12	5.15	6.02	7.06	7.36	7.65	8.43

Table 12 shows the average growth from winter to winter.

The sudden drop in growth rate after the first winter may be explained by the fact that the fish grow in depth more during this time than they do in length. There is generally a decrease in growth rate as the fish grows older. This decrease, as already mentioned, may be due to the attainment of sexual maturity (Graph 1).

TABLE 11

Average Length (Inches) of Bluegills at Buckeye Lake as Determined by Lee Roach and Irene Evans (1938)

	ANNULI							
	1	2	3	4	5	6	7	8
Length	1.69	2.92	4.23	5.56	6.75	7.55	8.19	8.75

TABLE 12

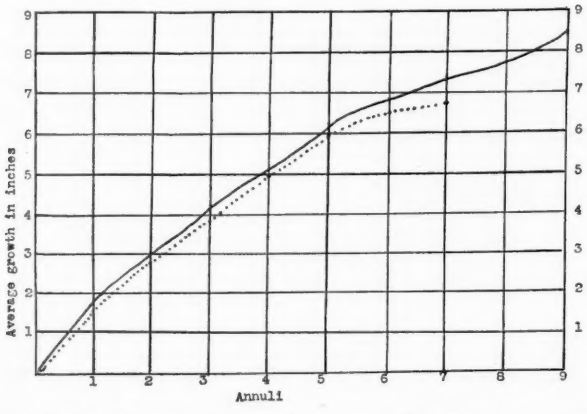
Growth (Inches) of Bluegills from Winter to Winter

	ANNULI								
	1	2	3	4	5	6	7	8	9
Growth	1.57	1.31	1.24	1.03	0.87	1.04	0.30	0.29	0.78

TABLE 13

Sex Differences in Growth (Inches)

	ANNULI								
	1	2	3	4	5	6	7	8	9
Males	1.42	2.75	3.89	4.97	5.85	6.56	6.75		
Females	1.62	2.92	4.27	5.16	6.23	6.83	7.40	7.65	8.43



GRAPH 4. Sex differences in growth. ——— Females. ..... Males

A comparison of growth rates of males and females is particularly interesting (Table 13 and Graph 4). The male bluegills at Buckeye Lake grow at a slower rate than do the females. The average length of all females was 6.62 inches. The average length of the male bluegills was 5.76 inches (Graph 4).

X. FOOD HABITS OF THE BLUEGILL

The successful angler is he who not only has studied the habits of the fish but who also frequently examines the contents of the stomachs of the fish he catches. Old timers, who have the reputation of being able to take fish out of a hole after others have spent hours in futile efforts, usually know the habits of the particular species of fish they are trying to capture. The food habits, which are of primary importance, are not the only factors.

The inability to catch fish often causes anglers to give the following alibis, "There are no fish in the lake," or "There is too much food in the lake and the fish are not hungry." Fishermen seldom realize that the abundance of food is very necessary to the production of large numbers of catchable fish. It is a recognized fact that there is a definite relation between the production of aquatic invertebrate fish food and the production of fish in any body of water. The most prolific source of this food is the shallow area along the shore where there is an abundance of aquatic vegetation. During the active growing season the bluegill may be found feeding in these areas.

An analysis of the stomach contents of 170 bluegills taken from test nets and from fishes caught by anglers during the spring and summer of 1949 revealed the following facts as to the food preference of the bluegill (Tables 14 and 15).

About 50 per cent of all the food taken were chironomids or midge larvae and pupae. The adults resemble large mosquitoes and often appear in clouds over the lake in the summer. Plant food made up 20.13 per cent of all the food taken. This consisted of vascular plants and Algae. Only about 1 per cent was Algae, the remainder being mostly the pond weed Najas and Ceratophyllum. Some of the stomachs contained 100 per cent plant food. These percentages are very near to the percentages given by Robert C. Ball (1) for the bluegill of Third Sister Lake, Michigan, 54.69 per cent being midge larvae, and 20.57 per cent being plant material. Table 15 shows the percentage of fishes having chironomids and other kinds of food in their stomachs.

E. W. McCormick (38), in a similar study of 100 bluegills from Reelfoot Lake, Tenn., stated that 52 per cent of the food of the bluegill was plant material, 34 per cent midge larvae, and 13 per cent other animal food. This high percentage of plant food of the bluegill seems to bear out the belief that plants make up an important part of the diet of this fish.

R. C. Ball (1), in his study of the seasonal relationship of plant food to invertebrate food gives the following percentage of plant food in the total volume of food for 1940:

	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER
Per cent.....	0	2	9	36	26	11	10	0

He states that the inference to be drawn from this study is that when the animal food supply diminishes during the summer bluegills turn to plant food as a substitute.

TABLE 14

Food of the Bluegills of Buckeye Lake (1949)

	MARCH	APRIL	MAY	JUNE	JULY	AVERAGE
NUMBER EXAMINED	4	9	91	60	7	
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
DIPTERA						
Chironomid larvae, Chironomid pupae	51	54.91	37.5	44.24	63.4	50.4
ODONATA						
Damselfly nymphs		16.48	7.5	5.78		9.58
TRICHOPTERA						
Caddis worms, Microcaddis worms	17.5		5.2	3.85		8.85
HEMIPTERA						
Adults				4.45		4.45
COLEOPTERA						
Donacia adults, Donacia larvae	3.6		1.2	8.57		4.45
NEUROPTERA						
Sialis larvae			0.15			0.15
MOLLUSCA						
Physa, Planorbis, Amnicola	2.5			0.16		1.33
ARACHNIDA						
Water mites		0.2	0.2	0.15		0.12
CRUSTACEA						
Hyallela, Gammarus	0.2		0.1	0.17		0.15
Crayfish	0.2		1.0		1.16	0.93
BRYOZOA						
Statoblasts of Pectinatella				0.11	0.25	0.12
FISH EGGS		22.21	29.1	8.76	7.25	16.82
PLANTS						
Ceratophyllum, Najas, Algae	25	6.2	18.22	23.76	27.5	20.13

Howell, Swingle and Smith (39) state, after their study of the food of the bluegill in Alabama waters, that although the bluegills do eat plant food they preferred animal food, preferably insects, and that when large quantities of plant

TABLE 15

Percentage of Total Fish Having Chironomids and Plants etc. in Their Stomachs

	PERCENTAGE OF TOTAL FISH
	per cent
DIPTERA Midge larvae, Midge pupae	53
PLANTS Najas, Ceratophyllum, Algae	34
FISH EGGS	28
ODONATA Damselfly nymphs	19.5
TRIHOPTERA Caddis worms, Microcaddis worms	9
CRUSTACEA Gammarus, Hyallela, Crayfish	8
COLEOPTERA Donacia larvae, Donacia adults	8
BRYOZOA Statoblasts of Pectinatella	7
HEMIPTERA Water bugs	4
ARACHNIDA Hydracarina, water mites	3
MOLLUSCA Physa, Planorbis, Amnicola	2.5
NEUROPTERA Sialis larvae	0.5

food are consumed it indicates that there are too many fishes in the pond or lake competing for the same animal food. This situation may also be true in Buckeye Lake. They also name the midge larvae as the most important bluegill food with the dragonfly nymph the next most common food. In Buckeye Lake the damselfly

is the third most abundant animal food of the bluegill, a total of 9.5 per cent. Not a single dragonfly nymph was recorded in this study.

In April, May, June and July, during the spawning period, bluegills of all sizes eat fish eggs. During these months an average of 16.82 per cent was recorded. Many stomachs were gorged with pumpkin seed eggs, eggs of the green sunfish, eggs of the large mouth bass and the gizzard shad. Caddis worms, beetle larvae, water fleas, water bugs, and water mites make up a sizable portion of the stomach contents of the bluegill.

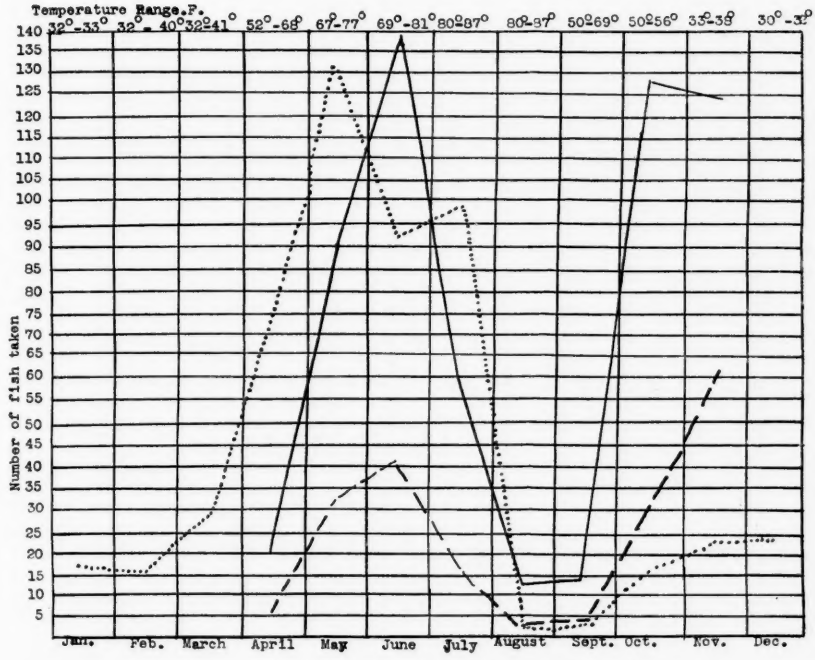
An unusual item of food of the bluegill was the statoblast of the Bryozoan Pectinatella. Colonies of these organisms are abundant in Buckeye Lake attached to piles supporting the wharfs along the water front. Colonies also float in the lake in masses as large or larger than a football.

Factors Influencing the Feeding Habits

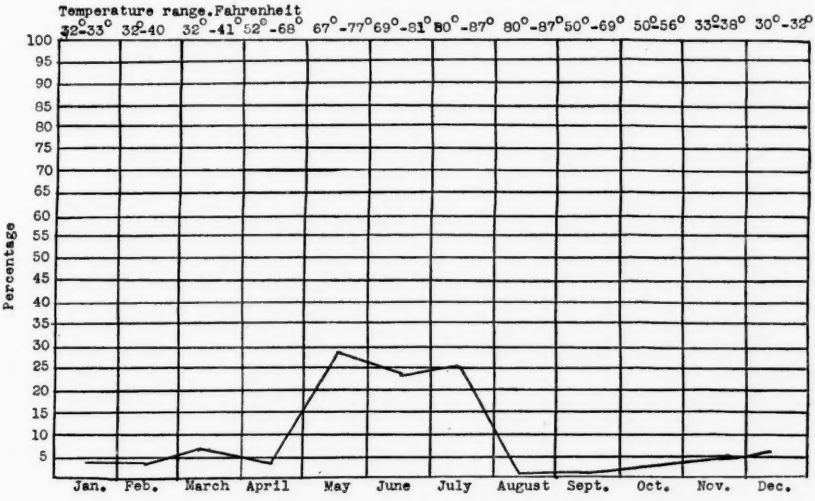
As already mentioned having a full stomach may be the reason why a fish refuses to bite, but this is only one of the factors which may influence the feeding activities.

Temperature. According to Belding (6) temperature has a profound effect on these activities. During the winter months when the water is very cold the activities of the fish are at a low ebb. The decreased body activities lower the energy needs so that many species require little or no food. Bluegills taken out of deep water in Buckeye Lake during the winter had midge larvae and plant material in their stomachs. These fish had an unusually large amount of fat wrapped about the alimentary canal. The organs in some cases were completely covered with fat. Probably more food was taken during these months than was necessary for body needs and hence the excess food was changed to fat. It was interesting to note that as the activities of the fish increased, when the water temperature rose in the spring, the fat completely disappeared.

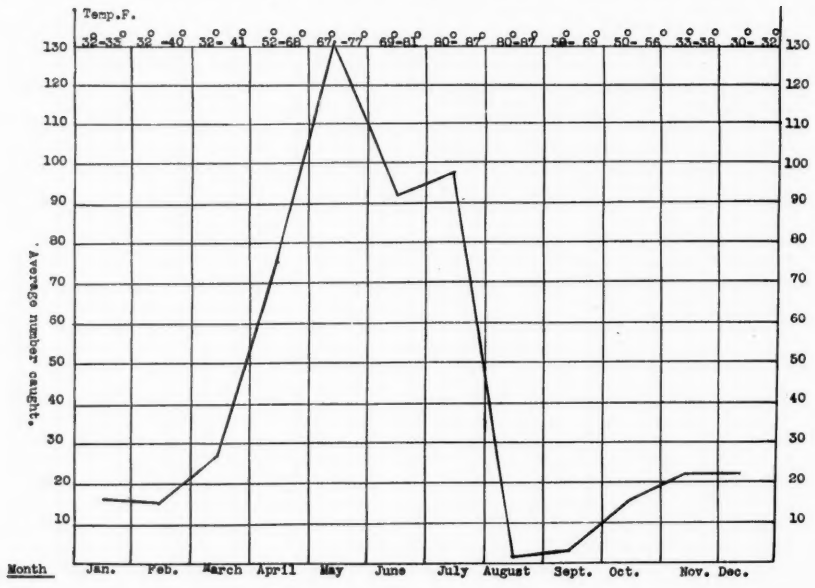
As water temperature increases during the spring the fish become more active and more food is required to satisfy body demands. However extreme rises in temperature may also cause the fish to stop eating. Graph 5 is a record of the test net catch and the fishermen's catch for 1949. Note that they are practically the same. *This seems to indicate that the test net catch is a good record of when the fish are biting.* Graphs 6, 7 and 8 are records of percentage, average number caught by fishermen per month and the number of bluegills taken in nets by the month. Note also that as the temperature increases during April, May and June the number of fishes taken increases. However, when a temperature of 80°F. is reached the number of fishes taken drops until in August with the temperature at 80° to 87°F. both the fishermen's catch and the test net catch is practically nil. Then as the temperature drops again in September and October there is a resumption of the feeding activities. However, it should be pointed out that this is not true of all fishes since various species of fish differ widely in their responses to temperature. David Belding (6) states that the Trout decrease their activity as the water temperature climbs to the seventies, while the bullheads do not appear to mind temperatures above this. It would be interesting to study the relation of temperature to the feeding activities of our fresh water game fishes.


Temperature Range.F.
32°-33° 32°-40° 32°-41° 52°-68° 67°-77° 69°-81° 80°-87° 80°-87° 50°-69° 50°-56° 33°-38° 30°-32°
Number of fish taken
Jan. Feb. March April May June July August Sept. Oct. Nov. Dec.

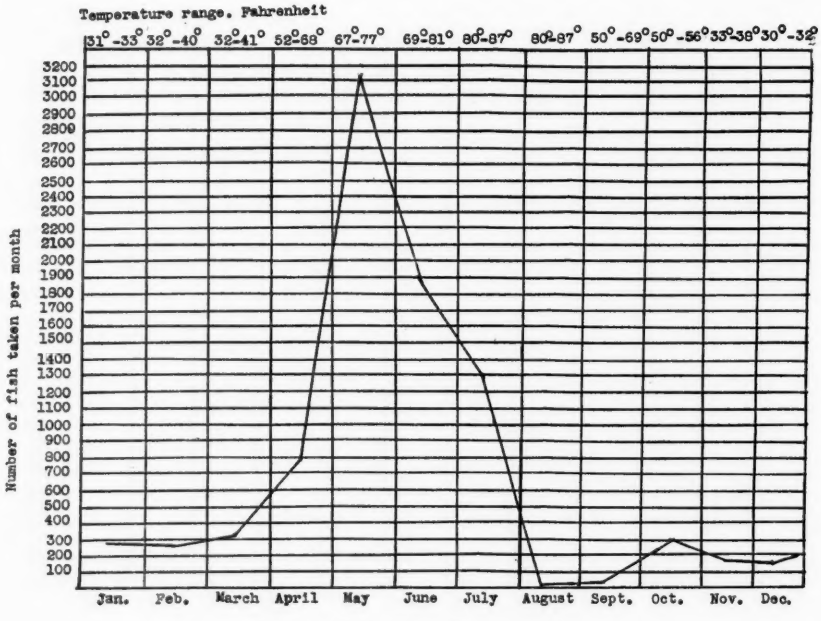
GRAPH 5. Monthly test net catch and fishermen's catch for 1949. ——— Average monthly catch per 100 Fishermen. — — — Average monthly catch per 100 hours of fishing. ..... Average monthly catch for each time the net was raised.


Temperature range.Fahrenheit
32°-33° 32°-40 32°-41° 52°-68° 67°-77° 69°-81° 80°-87° 80°-87° 50°-69° 50°-56° 33°-38° 30°-32°
Percentage
Jan. Feb. March April May June July August Sept. Oct. Nov. Dec.

GRAPH 6. Average percentage of bluegills taken for each time the net was raised

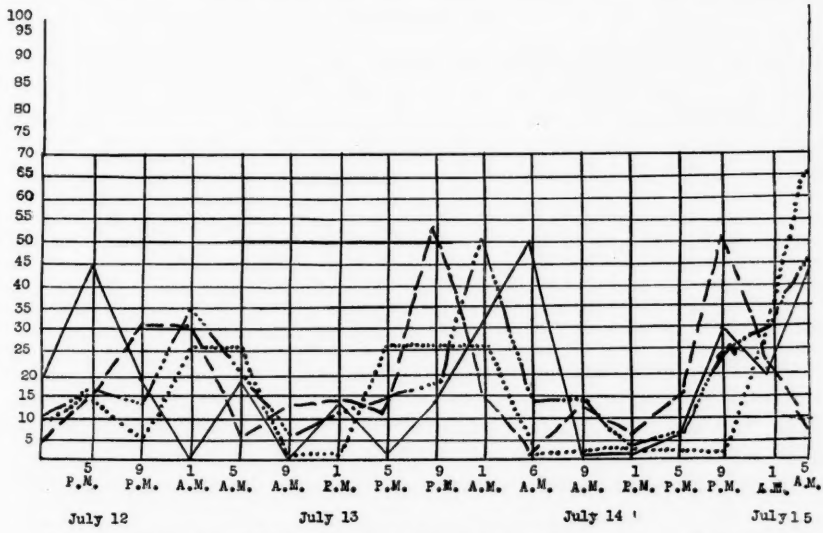

Temp.F.
31°-33° 32°-40° 32°-41° 52°-68° 67°-77° 69°-81° 80°-87° 80°-87° 50°-69° 50°-56° 33°-38° 30°-32°
Average number caught.
Month
Jan. Feb. March April May June July August Sept. Oct. Nov. Dec.

GRAPH 7. Lepomis macrochirus, the bluegill. Average number caught per month for each time the net was raised.


Temperature range. Fahrenheit
31°-33° 32°-40° 32°-41° 52°-68° 67°-77° 69°-81° 80°-87° 80°-87° 50°-69° 50°-56° 33°-38° 30°-32°
Number of fish taken per month
Jan. Feb. March April May June July August Sept. Oct. Nov. Dec.

GRAPH 8. Bluegill catch per month

Light. Light and time of the day may be another factor affecting the feeding activities of a fish. A study was made of the test net catch during certain periods of the day and night at Buckeye Lake. The net was raised every four hours for three and a half days. Graph 9 is a record of the catch of bluegills, black crappies, white crappies and all species every four hours. The peak of the catch for all fish each day was between 9 P.M. and 1 A.M. with very few fish taken between 9 A.M. and 5 P.M. Note that there is a slight variation in the catch of the different species. The peak for the white crappies was from 5 P.M. to 9 P.M. and another peak 1 A.M. and 5 A.M. The peaks for the black crappies was 5 P.M. to 9 P.M. and 9 P.M. to 5 A.M. The peak for the bluegills was between



GRAPH 9. Percentage of fish in test net at intervals of 4 hours.—— .... Total percentage of all species. ..... Percentage of bluegills. — — — Percentage of black crappies. ——— Percentage of white crappies.

9 P.M. and 5 A.M. However, a longer period of study of the time of the day catch would make this work more significant. It is generally believed that the increased nocturnal activity may be explained by the fact that the fish feel more secure from attack from enemies at night and hence use the cover of darkness for extensive feeding activities.

During cloudy weather and rain the feeding activities are increased. Some of the possible explanations given for this are Belding (6). Rain washes many land insects, earthworms, and other food into the stream, and also the increased stream flow may dislodge many aquatic animals from the vegetation to which they cling, and this sudden abundance of food may stimulate the feeding activities of the fish. Also rain brings an increased supply of oxygen to the water and this may be responsible for the increased activity.

Spawning period. During the spawning period the bluegill is most active in its

feeding habits. Note that Graph 5 of the test net catch and the creel census, and Graph 2 of the spawning period are practically the same. The increased activity during this period increases the energy requirements which the fish makes up by increased feeding.

Bait. Bluegills will bite at any bait when hungry: earthworms, crickets, grasshoppers, catalpa worms, damselfly nymphs, dragonfly nymphs and the artificial fly. Trautman (36), fishing at Whitmore Lake, Michigan, claims that 80 per cent of the bluegills caught by him and other fishermen were taken with the fly at the surface in the evening. The majority of the large bluegills, 7 to 8 inches, were taken in deep water. Small bluegills seldom penetrate depths beyond 15 to 20 feet.

XII. PREDATORS

A great number of bluegill fry are eaten by the large mouth bass, white crappies, black crappies, white bass and other fish. The eggs are devoured by all kinds of sunfish, crayfish, and by some of the larger aquatic insects. Large mouth bass are capable of devouring bluegills up to five inches in length. W. E. Ricker (27) claims that the following fishes are capable of swallowing 5 inch bluegills:

Bowfin, Amia Calva
The Gar, Lepidosteus productus
Large Mouth Bass, Aplites salmoides
Northern Pike, Esox lucius
Long nose Gar, Lepidosteus osseus
Small Mouth Bass, Micropterus dolomieu

Of these only the large mouth bass is present in Buckeye Lake.

Herons are also fish predators and catch some of the bluegills of Buckeye Lake. This loss, however, is not large because of the small population of herons. Wild ducks also remove numbers of fish from the lake.

W. E. Ricker (27) also claims that the following turtles are predators of fish:

Musk turtle, Stenotherus
Painted turtle, Chrysemus picta
Blanding's turtle, Emys blandingii
Map turtle, Graptemys geographica
Soft shell turtle, Amyda guttata
Snapping turtle, Chelydra serpentina

I saw a large crayfish stalk a bluegill which was guarding the nest at Buckeye Lake. The crayfish moved forward very slowly until he was directly beneath the fish. Then he made a quick lunge and grasped the fish about the middle of the body with one of his powerful pincers. The fish was held helpless, incapable of moving in any direction. It struggled in the grasp of the crayfish for more than five minutes when I rescued it with a dip net.

XIII. PARASITES

A study of the parasites of fishes of Buckeye Lake was conducted by Ralph V. Bangham of the College of Wooster as a part of a survey conducted by the

Ohio Division of Wildlife. The parasites of the bluegill Lepomis macrochirus was included in this study. I am indebted to Dr. Bangham's paper (2) for the following information.

Of 39 specimens of bluegills examined 34 were found to be parasitized. These include larval and adult Cestodes, encysted Acanthocephala, Trematodes, parasitic Nematodes and parasitic Copepods. The Cestodes included the larval stages of the tapeworm Protocephalus ambloplitis (leidy) found encysted in the liver.

Acanthocephala. These worms are characterized by having a large body cavity, a complete lack of digestive tract, a spiny proboscis which is retractile into a sac, and separate sexes. Of these 12 Leptorhynchoides thecalus, and 5 Neoechinorhynchus cylindratus were found encysted in the livers. Three adult Leptorhynchoides were taken from the intestinal tract.

The Trematodes include the gill flukes of the family Gyrodactylidae.

Parasitic Copepods included:

9 Ergasilus caeruleus
20 Ergasilus centrarchidarum.

I also found one specimen of Argulus species (?).

The Nematode worms included:

5 adult Spinitectus carolini Holl
6 adult Camallanus oxycephalus (Van Cleave)
2 encysted Agamomema sp.

Annelida—two leeches.

XIV. ECONOMIC VALUE

The bluegill is considered by anglers as the favorite pan fish of our lakes. Its flesh is firm, flaky, and tasty. The number of bluegills in the creel census at Buckeye Lake for 1949 was 10290 fishes, each averaging about $\frac{1}{4}$ of a pound. This is a total of 2572 pounds of fish taken from Buckeye Lake alone. This is but a low estimate since it is not possible to get data of all the bluegills taken out of the lake by fishermen.

The bluegill is one of the favorite fishes for stocking farm ponds. It becomes easily adapted to pond conditions. The large number of farm ponds in the State and the increasing interest in farm ponds boosts the economic value of this popular pan fish.

Bluegills are also important as forage fish in our hatcheries in the production of large mouth bass and small mouth bass. The ease by which it propagates itself is an important factor in its selection as a source of food for these game fishes. During its early development it is also an important source of food for such fish of our lakes as the crappies, white bass, large and small mouth bass, perch, pike perch and bullheads.

Commercially they are not so important because the bluegill does not get as large as the white fish, pike perch, yellow perch and the bullheads.

XV. SUMMARY

1. The life history of the bluegill was studied at Buckeye Lake during 1949 and 1950. Buckeye Lake is a shallow fresh water lake situated about 27 miles from the city of Columbus, Ohio, and about 15 miles from the city of Newark, Ohio.

2. Bluegills are most active in the shallow water along the shore between March and August. The most active periods are in May, June, July and early August. This corresponds with the spawning period of the species. During the warmer days of the summer when the temperature reaches 80 or more degrees Fahrenheit few bluegills are taken either in the test nets or by fisherman. This may be due to migration to deeper water, decreased food supply or lack of activity due to the warmer waters.

3. They are associated both diurnally and nocturnally with the white crappie and the black crappie, bullheads, shad, and white bass. During early spring and early summer they are usually taken with these fish in the test nets.

4. The attainment of sexual maturity varies in the bluegill. Some workers claim that bluegills may become sexually mature the second summer (one year old) by increased feeding. These fishes may attain a length of four inches during the first year. Buckeye Lake fishes do not attain this length until the third or fourth summers, two years old and three years old respectively. Also, no mature one year old bluegills were taken in this study.

5. Bluegills spawn from early May to the middle of August.

6. Nests may be found in sand and small pebbles, in matted vegetation on the bottom, and even in mud with dead twigs and leaves. The nests vary in size from about eight inches to about two feet in diameter and from two to three inches in depth. They may be found in water from about a foot to five feet in depth.

7. The eggs are dropped above the nest and are fertilized as they settle to the bottom where they adhere to small pebbles, vegetation or dead twigs or leaves. Mature eggs are about 1.26 mm. in diameter.

8. The number of eggs produced varies with the size of the fish from 2540 in 4 to $4\frac{1}{2}$ inch fish to 49400 in an $8\frac{3}{4}$ to 9 inch fish. The average number for all fishes studied at Buckeye Lake was about 18300.

9. The incubation period varies from 31 hours and 50 minutes to 62 hours at a temperature of 72° to 73°F.

10. The total length of a bluegill larva at hatching is 2.79 mm. At eight days the post larva measures 5.04 mm. The total length of a three to four weeks old fry is about 14.5 mm.

11. The male bluegill protects the nest for two to three days hence the tiny larvae lying at the bottom of the nest are given some protection.

12. The number of fry varies with the number of eggs produced and with the number of predators present. Carbine (8) found that a nest contained 4670 to 61,815 fry with an average of 17,914 fry per nest. The largest school we encountered was about 5000 fry. According to C. Oldham this agrees with the count at the Federal Fish Hatchery at Hebron. The mortality between the eggs produced and the number of fry is quite high.

13. The yearly growth varies in the species, as is expected. The first year's growth to the formation of the first annulus varies from 1.13 inches to 2.38

inches. This may be due to the date of hatching. Those that hatch early in the summer have a longer period to grow than those that hatch late in the summer. The average second year's growth is about 1.31 inches. After spawning, in a majority of cases, there is a drop in the yearly growth rate to between 0.61 and 1.15 inches. This reduced growth rate continues during the succeeding years.

14. The average rate of growth of male bluegills of Buckeye Lake is below that of the females.

15. Chironomids make up the greatest percentage of food of the bluegill. Plants represent the second most abundant food eaten by the bluegill. During the spawning period fish eggs make up a good portion of the food taken.

16. The creel census and the test net catches of bluegills are almost identical. Therefore it is assumed that a high test net catch is indicative of the feeding and biting activities of the fish. From our study of the test net catches at four hour intervals it appears that the most active period is between 5 P.M. and 5 A.M. This is also true of other game fishes.

17. Of the 39 specimens of bluegills of Buckeye Lake examined by R. V. Bangham (2), 34 were found to be parasitized.

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THE REACTION OF 2-METHYLDIHYDROBENZOFURAN WITH *n*-BUTYLLITHIUM[1]

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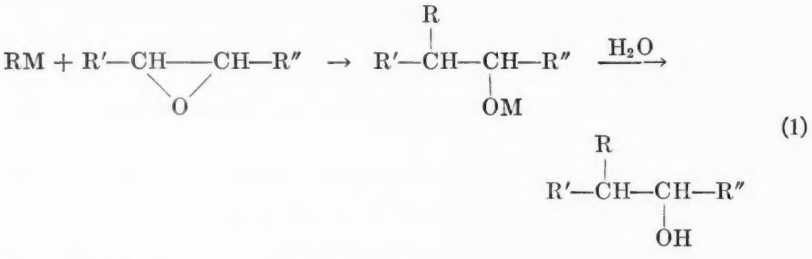
The investigation reported herein was designed to extend the knowledge of reactions occurring between cyclic ethers and strong bases of the organometallic class. Such reactions have been extensively studied by numerous investigators (1). Because of their unusual reactivity as ethers, epoxides have received particular attention (1). Recently a study of the less reactive trimethylene oxide has been reported (2). With either epoxides or trimethylene oxide, the product generally to be expected can be thought of as arising from a displacement type reaction (3a) such as that pictured in equation 1.



(1)

R = any alkyl group
R′ and R″ = alkyl groups or H
M = metal (RM usually Grignard or organolithium compound)

Some reports indicated that Grignard reagents reacted to give products that could be pictured as arising from the reaction of the organometallic reagent with an aldehyde or ketone which itself had been formed by a rearrangement of the epoxide (1c, e). However it was demonstrated conclusively that this rearrangement is brought about by the inorganic magnesium halide usually present in Grignard solutions and is not a characteristic reaction of the organometallic compound itself. When the magnesium halide is removed from the solutions, only the normal displacement product is obtained (1a, c).

Under certain conditions, however, products other than the displacement type may be observed. Thus when cyclohexene oxide was treated with a stronger base than a Grignard reagent (isopropyllithium), 2-cyclohexenol was isolated

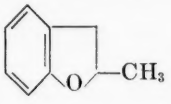
[1] Contribution from the Chemical Laboratories of Northwestern University and Denison University.

[2] Assistant Professor of Chemistry, Denison University.

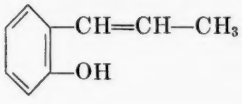
as the main product.[3] Although this product cannot be expected to arise from any reaction such as is shown in equation 1, a metallation reaction followed by an elimination type rearrangement (3b) of the epoxide anion seems a reasonable postulate for the course of the reaction. In at least one instance, this elimination type product was observed when a Grignard reagent was employed, but only after special treatment of the reaction mixture (4).

It seemed of interest then to extend the studies to the less-reactive cyclic ethers such as those containing five-membered rings. The decrease in activity should perhaps preclude a displacement type reaction, but not necessarily an elimination type one. Because it is readily available, 2-methyldihydrobenzofuran (formula A) was chosen for this investigation. When this compound was treated in ether solution with *n*-butyllithium and the reaction mixture was subsequently carbonated, two products were isolated. One of these, the major product (70 per cent), was a carboxylic acid. The other (5.6 per cent) was an unsaturated phenol, proved by independent synthesis to be 2-propenylphenol (formula B).

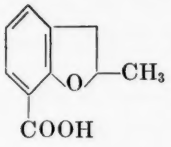
Although attempts to prove the structure of the carboxylic acid have been unsuccessful, the acid is believed to be 2-methyl-7-carboxy-dihydrobenzofuran (formula C), a compound previously unreported. Metallation by *n*-butyllithium



A

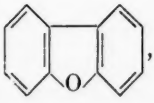


B



C

in the dihydrofuran ring of A gives an anion which may rearrange as postulated below. Metallation in the benzene ring, however, should give a stable anion which would react with carbon dioxide to give the carboxylic acid. Gilman (5) has shown that dibenzofuran,



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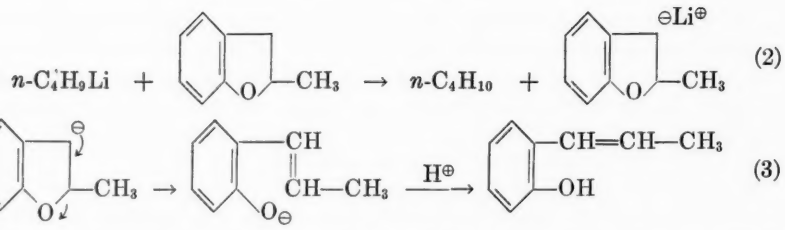
is metallated by methyllithium or *n*-butyllithium in positions *ortho* to the oxygen. In view of this and the facts that 5-carboxy-2-methyldihydrobenzofuran is reported (6) to melt at 150° whereas the carboxylic acid isolated in this study melts at 128°, 2-methyl-7-carboxydihydrobenzofuran (C) is proposed as the structure of the acid obtained.

The minor product, 2-propenylphenol (B), is believed to be formed by a metallation of the 3-position of the starting material, followed by an elimination-type rearrangement of the anion thus formed.

[3] Unpublished results of R. L. Letsinger and J. G. Traynham; see J. G. Traynham, Ph.D. Dissertation, Northwestern University, 1950.



The reactions leading to 2-propenylphenol have been pictured as an attack at the position β to the oxygen although the possibility of an attack at the α-position has not been excluded. The formulation of the reaction as a β-elimination is in line with the picture usually given for elimination reactions in general. Further research in relation to the course of this reaction is anticipated.

Acknowledgement. Part of the work reported here was supported by a research grant from the Denison University Research Foundation. For this financial assistance the author is sincerely grateful.

Experimental

2-Methyldihydrobenzofuran. Allyl phenyl ether[4] (200 g., 1.49 moles) was refluxed under a nitrogen atmosphere for 6.5 hours. During this time the temperature of the refluxing liquid rose from 190° to 218°. In order to remove any unrearranged material, the liquid was treated according to the procedure given by Tarbell (7). After evaporation of the ether, the undistilled, colorless 2-allylphenol was rearranged to 2-methyldihydrobenzofuran by refluxing for 25 minutes with 400 ml. of 48% HBr and 800 ml. of acetic acid. From the mixture was isolated (7) 91.0 g. (45.5% overall) of 2-methyldihydrobenzofuran boiling at 73° (14 mm.) after two distillations; n^{25}_D 1.5292.

Reaction with *n*-butyllithium. An ether solution of *n*-butyllithium was prepared (8) from 8-mesh lithium shot and *n*-butyl bromide. Centrifuging gave a clear, colorless solution which was found by titration (9) to be 1.405 molar in *n*-butyllithium. To 295 ml. of this solution (0.42 mole of *n*-butyllithium) was added 53.6 g. (0.40 mole) of 2-methyldihydrobenzofuran. After refluxing with stirring under a nitrogen atmosphere for 42 hours, the reaction mixture was siphoned into a stirred slurry of carbon dioxide-snow in ether.[5]

The carbonated mixture was extracted three times with 15% NaOH solution. The neutral ether layer was washed with water, dried over anhydrous $CaSO_4$,

[4] The product purchased from Dow Chemical Company, Midland, Mich., was used without further purification.

[5] In another run, when the mixture was siphoned onto Dry Ice alone, a ketone rather than a carboxylic acid was isolated in good yield (see ref. 11); m.p. 55.5–56.5°; 2,4-dinitrophenylhydrazone derivative, m.p. 159–160°. This ketone afforded no useful information regarding structure, but on the basis of the proposed structure for the carboxylic acid, the compound is thought to be di-(2-methyldihydro-7-benzofuryl) ketone.

and distilled. In addition to ether and higher-boiling fractions, 3.4 g. (6.3%) of starting material was recovered.

The combined NaOH-extracts were saturated with carbon dioxide and then extracted three times with ether. This ether solution was dried over $CaSO_4$ and distilled to yield 2.8 g. (5.6%, based on unrecovered starting material) of a phenolic product boiling at 96° (4 mm.). This material solidified in the receiver; n^{25}_D 1.5756 (fused state). The phenoxyacetic acid derivative (10) melted at 113.5–115°.

The aqueous solution from above ($NaHCO_3$ solution) was made acid with dilute HCl; the tan solid that separated was collected with suction and dried in a vacuum desiccator. Yield, 47.1 g. (70%, based on unrecovered starting material). After recrystallization from alcohol, the white crystals melted at 128–128.5°. This acid product gave no color change with $FeCl_3$ solution, nor did it give any positive test for unsaturation.

Of the original 2-methyldihydrobenzofuran introduced into the reaction, 82% is accounted for by recovered starting material, the phenolic product, and the carboxylic acid product. The remainder was present as intermediate fractions or undistilled residues in the distillations.

2-Propenylphenol. With alcoholic KOH, 2-allylphenol was isomerized (7) in good yield to 2-propenylphenol, b.p. 97–99° (5 mm.); n^{25}_D 1.5760 (fused state). The phenoxyacetic acid derivative (10) melted at 115–115.5°. When a sample was mixed with the phenoxyacetic acid described above, the melting point was not depressed.

Summary

Metallation of 2-methyldihydrobenzofuran with *n*-butyllithium followed by carbonation, is found to give two products: 2-propenylphenol and an acid thought to be 2-methyl-7-carboxydihydrobenzofuran. A mechanism for the formation of the phenolic product is proposed.

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